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A2136-1 (REV. 6-61)

DETERMINATION OF THE EFFECT OF OXYGEN CONTENT ON THE MECHANICAL PROPERTIES OF TITANIUM -5 Al-2.5 Sn ALLOY AT ROOM AND CRYOGENIC TEMPERATURES.

MRG 266

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GENERAL DYNAMICS/CONVAIR

SUBJECT: Determination of the Effect of Oxygen Content on the Mechanical Properties of Titanium - 5 Al-2.5 Sn Alloy At Room and Cryogenic Temperatures.

ABSTRACT: Tensile (F_{ty}, F_{tu} and elongation) properties, notched tensile strengths and notched/unnotched tensile ratios were determined on five heats of Ti-5Al-2.5 Sn at +78°, -320°, and -423°F. Oxygen analyses of the five heats were .09, .11, .15, .17 and .24 weight percent. The data obtained show an increase in tensile and yield strengths at all testing temperatures with an increase in oxygen content. Elongations remained nearly constant except for the .24% O_2 heat at -423°F which exhibited a sharp decrease in elongation. Notched tensile strengths and notched/unnotched tensile strength ratios indicate a high degree of toughness for all of the heats at +78° and -320°F. At -423°F those heats containing under 0.15% oxygen were tough, the heat containing 0.15% oxygen began to show embrittlement due to oxygen, while heats with increasing oxygen contents were progressively more brittle. It is recommended that the oxygen content of the Ti-5Al-2.5 Sn Alloy be limited to a maximum of 0.12% in order to insure adequate toughness for structural applications at liquid hydrogen temperature (-423°F).

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SUBJECT: Determination of the Effect of Oxygen Content on the Mechanical Properties of Titanium - 5 Al-2.5 Sn Alloy at Room and Cryogenic Temperatures.

INTRODUCTION

The mechanical properties of a large number of titanium alloys have been determined and have been presented in Reports Nos. MRG-189, MRG-213, MRG-246, MRG-249, and MRG-262. Of the alloys investigated the Ti-5Al-2.5 Sn alloy showed the most promise for structural applications at -423°F. It was noted, however, that some heats were appreciably tougher than other heats at extreme sub-zero temperatures. It was felt that the interstitial elements (C, O_2, H_2 and N_2) were responsible for the variations in toughness from one heat to another. The present investigation was made to determine the effect of oxygen content (from 0.09 to 0.24 weight per cent) upon the tensile properties and toughness of the Ti-5Al-2.5 Sn alloy at 78, -320 and -423°F.

MATERIALS

Five heats of Ti-5Al-2.5 Sn alloy containing various amounts of oxygen were supplied by the Titanium Metals Corporation of America. The material was furnished in the form of laboratory rolled sheet 8" x 12" to 16" in size and thicknesses in the range of 0.038" to 0.043". Chemical analyses and some mechanical property data as supplied by Titanium Metals Corporation of America are given in Table 1. Except for the iron in heat V-1670, the Al, Sn, Fe, C, N_2 and H_2 were held at nearly the same level in all five heats. The material was tested in the "as received" (mill-annealed) condition.

PROCEDURE

Blanks for tensile specimens, 9" x 1½", were identified and sheared parallel to the direction of rolling (all specimens tested were longitudinal). Smooth specimens were machined per drawing MRG-D-1 and notched specimens per drawing MRG-D-10, Notch "A". The notched specimens were inspected and notch radii and width between notches measured by an optical comparator. Tests were performed at +78°F (room temperature), -320°F (immersion in liquid nitrogen) and -423°F (immersion in liquid hydrogen). Strain measurements were made by use of extensometers. Strain rates were 0.001"/"/min. up to the 0.2% offset yield point and 0.15"/min. from yield until fracture. Elongations are reported as the total elongation over a 2" gauge length.

RESULTS AND DISCUSSION

The mechanical properties of the five heats of Ti-5Al-2.5 Sn alloy at +78°, -320° and -423°F are reported in Table II. As has been previously experienced, the yield and tensile strengths increase about 100% upon reducing the test temperature from +78° to -423°F. The test temperature appears to have little effect upon the elongation except for the high (0.24%) oxygen heat (V-1671), where the elongation was severely decreased from -320°F to -423°F. The yield and tensile strengths generally increase with increase in oxygen content, which would be expected.

The toughness of the Ti-5Al-2.5 Sn, as evaluated by notched tensile strengths and notched/unnotched tensile strength ratios, is definitely affected by the oxygen content. The notched tensile strength continuously increases with reduction in test temperature for those heats containing 0.09 and 0.11% oxygen (heats V-1699 and V-1668), while the heat containing 0.15% oxygen (heat V-1669) shows only a very slight increase in notched tensile strength between -320°F and -423°F. The heats containing 0.17 and 0.24% oxygen (heats V-1670 and V-1671) show a significant decrease in notched tensile strength as the temperature is reduced from -320°F to -423°F.

Tough, crack-resistant metals show a continuous increase in both smooth and notched tensile strength with decreasing temperature of test. The change in notched tensile test with decreasing temperature, as well as the notched/unnotched tensile strength ratio, may therefore be taken as an index of brittle fracture tendency. The net change in notched tensile strength between -320°F and -423°F for all heats is plotted against oxygen content in Figure 1. It is seen that at oxygen levels of 0.09 and 0.11%, the notched tensile strength increases approximately 25,000 psi from -320°F to -423°F. At an oxygen level of 0.15%, the increase in notched tensile strength is only 3,000 psi between these two temperatures, while at 0.17 and 0.24% oxygen, the notched tensile strength decreases 18,000 and 40,000 psi respectively between -320°F and -423°F. The smooth curve through these points definitely justifies the 0.12% maximum limit which has been placed upon the oxygen content in General Dynamics/Astronautics Specification No. 0-71010.

The effect of oxygen content upon the notched/unnotched tensile strength ratios at the various test temperatures is shown below:

Oxygen Content Wt. Percent	Notched/Unnotched Tensile Strength Ratio (Longitudinal tests) +78°F	-320°F	-423°F
.09	1.34	1.25	1.14
.11	1.38	1.27	1.10
.15	1.35	1.24	1.02
.17	1.36	1.23	0.91
.24	1.40	1.17	0.78

RESULTS AND DISCUSSION (continued)

The above data show that oxygen content over the range of 0.09 to 0.24% does not influence the room temperature toughness of the 5Al-2.5 Sn-Ti alloy, as evaluated by means of a notched tensile specimen having a stress concentration factor, K_t, of 6.3. The same test when performed at -320°F begins to show some degradation in toughness at an oxygen level of 0.24% while at -423°F, the notched/unnotched tensile strength drops to unity at an oxygen level of 0.15% and is significantly reduced at higher oxygen contents.

Based upon the results obtained, it is concluded that the specification for 5Al-2.5 Sn-Ti alloy sheet to be used for liquid hydrogen temperature applications should limit the oxygen content to a maximum of 0.12% in order to assure adequate toughness for such applications.

SUMMARY:

1. Yield and tensile strengths of the Ti-5Al-2.5 Sn alloy increase about 100% with decrease in test temperature from 78°F to -423°F.

2. Elongation is only slightly affected by decrease in temp. except for the high oxygen (0.24%) bearing heat. The elongation of this heat is sharply reduced from -320°F to -423°F.

3. The toughness of the Ti-5Al-2.5 Sn alloy, as determined by notched tensile data and notched/unnotched tensile ratios, is definitely affected by increase of oxygen.

4. It is recommended that the O_2 content be limited to 0.10 to 0.12% (0.15% maximum) in order to assure adequate toughness at -423°F.

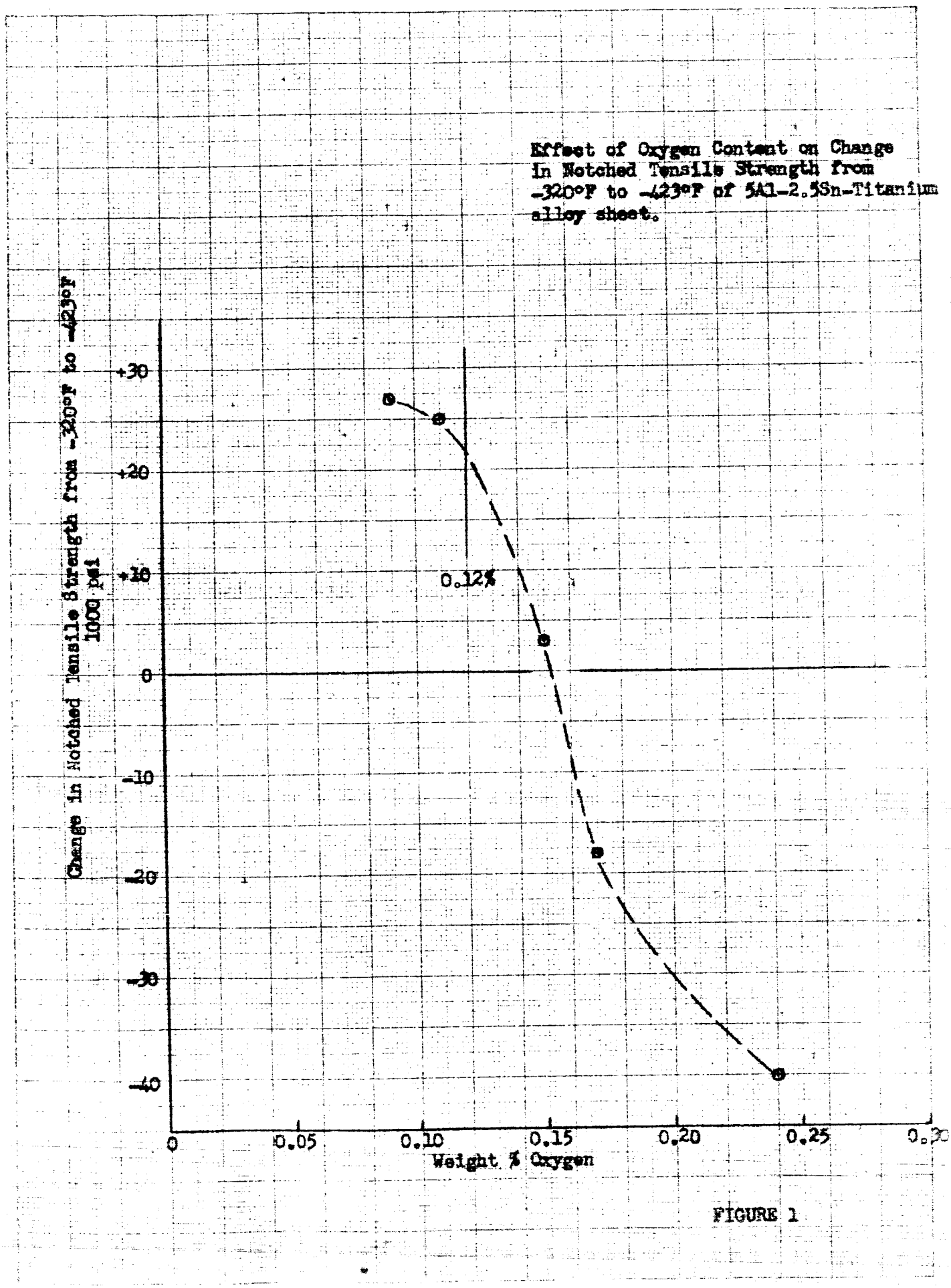
Effect of Oxygen Content on Change In Notched Tensile Strength from -320°F to -423°F of 5Al-2.5Sn-Titanium alloy sheet.
Change in Notched Tensile Strength from -320°F to -423°F 1000 psi
+30
+20
+10
0
-10
-20
-30
-40
0.12%
0
0.05
0.10
0.15
0.20
0.25
0.30
Weight % Oxygen

FIGURE 1